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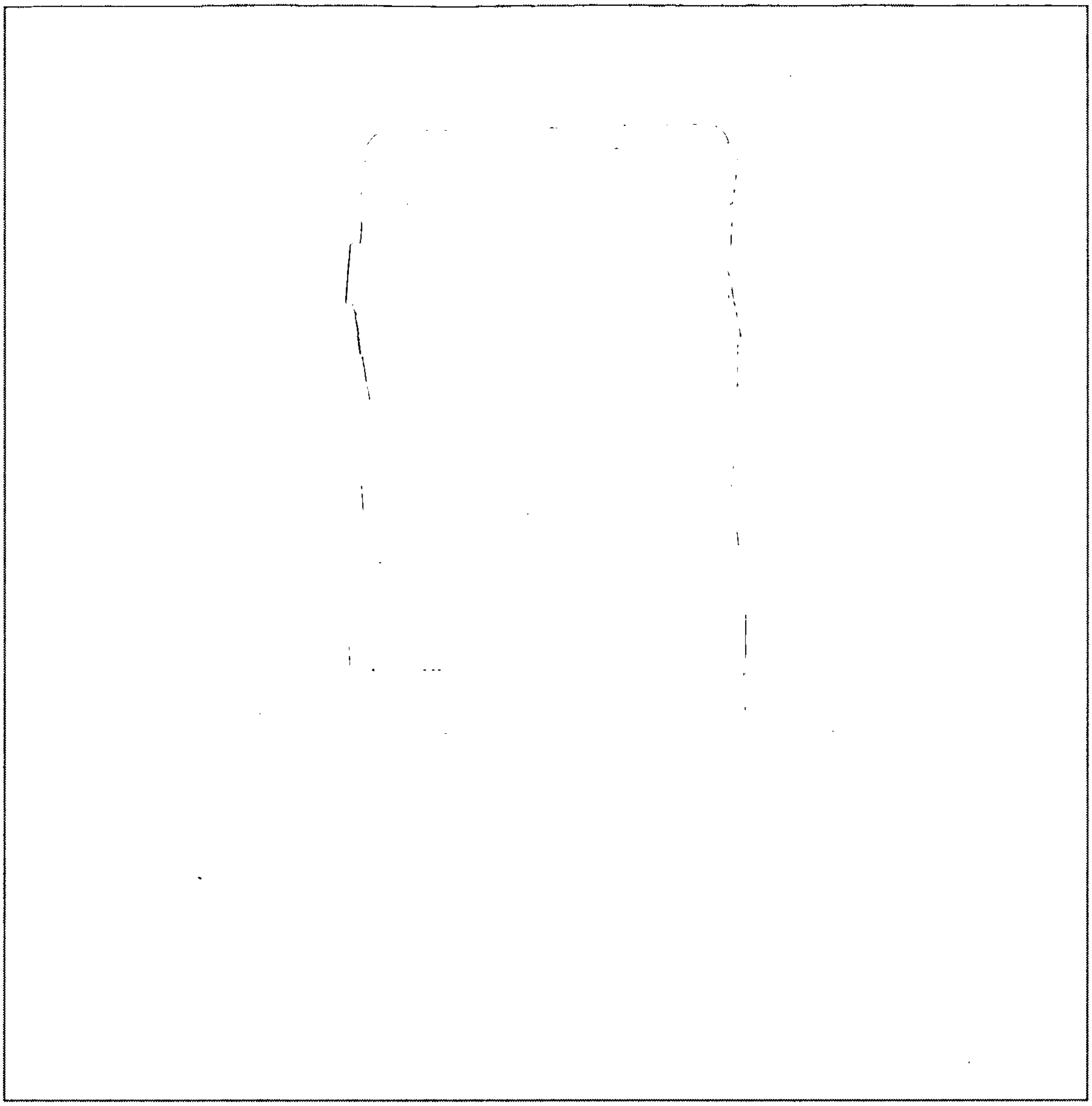
ABSTRACT

This paper focuses on the importance of inquiry in the development of scientific knowledge and includes recommendations for inquiry teaching in higher education, especially in preservice teacher education. Some of the recommendations include: (1) students should engage in inquiry early; (2) teachers should be able to effectively ask questions and listen to answers; and (3) students should be able to collect and analyze data. (Contains 17 references.) (YDS)

Standards for the Education of Teachers in Science: Teaching through Inquiry.



The NSTA Standards for Education of Teachers of Science were not written by the authors of this paper set, but are included in their entirety within the article. All standards are shown with a light blue background. Text by the authors of this article is on white and grey backgrounds.

Each of the ten standards was written collaboratively. This standard, Teaching Through Inquiry, was developed under the leadership of Larry Flick.

Standards for the Education of Teachers in Science: Inquiry

The program prepares candidates to engage students regularly and effectively in science inquiry and facilitate understanding of the role inquiry plays in the development of scientific knowledge. Inquiry refers to:

- Questioning and formulating solvable problems.
- Reflecting on, and constructing, knowledge from data.
- Collaborating and exchanging information while seeking solutions.
- Developing concepts and relationships from empirical experience.

3.1 Examples of Indicators

3.1.1 Preservice Level	3.1.2 Induction Level	3.1.3 Professional Level
A. Plans and implements data-based activities requiring students to reflect upon their findings, make inferences, and link new ideas to preexisting knowledge.	A. Regularly requires students to collect, reflect upon and interpret data, to report the results of their work, and to identify new problems for investigation.	A. Consistently engages students in critical discussion about the results of their inquiry, interpretations of their results, the implications of their conclusions and possible new problems.
B. Plans and implements activities with different structures for inquiry including inductive (exploratory), correlational and deductive (experimental) studies.	B. Involves students in diverse investigations, analysis of investigative structures and discussion of criteria for analyzing outcomes.	B. Systematically integrates investigations with different formats into classroom work, and relates student work to research traditions that typify the various sciences.
C. Uses questions to encourage inquiry and probe for divergent student responses, encouraging student questions and responding with questions when appropriate.	C. Regularly uses divergent and stimulating questioning to define problems and stimulate reflection; leads students to develop questions appropriate for inquiry in a given area.	C. Skillfully facilitates classroom discourse through questioning, reflecting on, and critically analyzing ideas, leading students toward a deeper understanding of the inquiry process itself. Uses questions to define problems and potential solutions.
D. Encourages productive peer interactions and plans both individual and small group activities to facilitate inquiry.	D. Systematically provides students with opportunities to engage in inquiry with peers using a variety of formats.	D. Skillfully meshes opportunities for science-related inquiry with critical reflection on the role of the individual as an inquirer in a collective context.

3.2 Rationale and Discussion

Understanding the process of inquiry as it occurs in a classroom is a complex task. Inquiry cannot be reduced to a set of steps called "the scientific method" any more than chess can be reduced to an algorithmic set of moves based on a few rules. Specific processes of inquiry (like chess moves) must be taught and understood, but the reason for engaging students in inquiry goes beyond the development of isolated skills to the inculcation of an approach or attitude toward engagement with the world. John Dewey (1958) described inquiry as a dialectical relationship betweenthe inquirer and the inquired. Evelyn Keller (1985) described this relationship as "dynamic objectivity." Research on teaching through inquiry reflects the dynamic and multifaceted nature of this construct.

Inquiry involves the development and use of higher-order thinking to address open-ended problems. Resnick

(1987) describes higher order thinking as nonalgorithmic and complex. The path to a solution is not discernible from a single vantage point. Multiple solutions are possible, and the inquirer may have to use multiple, sometimes conflicting, criteria to evaluate his or her options. Inquiry is characterized by a degree of uncertainty about outcomes. True inquiry ends with an elaboration and judgement that depends upon the previous reasoning process.

Traditionally, critical thinking has been embedded in the application of various science processes. Schwab (1962), for example, wanted instructional labs to offer opportunities for miniature scientific investigations. To that end, he proposed that teachers present lab problems at three levels for the purpose of developing an orientation to inquiry. At the first level, teachers present problems not discussed in the text, with descriptions of different ways to approach the solution. At the second level, teachers pose problems without methodological suggestions. At the third level, teachers present phenomena designed to stimulate problem identification. Each level requires more facility in using process skills than the previous level.

Trowbridge and Bybee (1990) also discuss three levels inquiry, beginning with *discovery learning*, in which the teacher sets up the problem and processes but allows the students to identify alternative outcomes. The next level of complexity is *guided inquiry*, in which the teacher poses the problem and the students determine both processes and solutions. The third, and most demanding level is *open inquiry*, in which the teacher merely provides the context for solving problems that students then identify and solve.

Questions that promote inquiry and lead to conceptual discussion are important for the success of inquiry teaching and learning (Dantonio, 1987). Since the purpose of inquiry is to lead students to construct their own knowledge, questioning is an important skill. Rowe (1973) examined the verbal behavior of teachers while they were engaging students in activities emphasizing science processes. Her work showed that high levels of teacher sanctions during classroom interactions were counterproductive, leading students to respond to questions to receive teacher rewards rather than to further the classroom investigation. She identified wait-time as a powerful influence on the length, frequency, and level of student responses, both for the teacher and students. Tobin (1987) reviewed work on wait-time over a twenty-year period and found similar results.

In the 1980's the focus of research shifted to children's intuitive ideas in science (Driver, Guesne, & Tiberghien, 1985; Osborne & Freyberg, 1985). The importance of the prior cognitive states of the learner, including specific preconceptions about the natural world, led to a reconsideration of the context and purposes of inquiry (Roth, Anderson, & Smith, 1987). Many scholars abandoned the view that inquiry processes and problem solving skills can be learned outside the context of a specific conceptual problem (Millar & Driver, 1987). This line of research led to the development of mediated forms of inquiry, in which the role of the teacher is to elicit students' existing science knowledge, introduce new ideas in the context of hands-on/minds-on activities, and modify learners' ideas towards accepted scientific concepts (Driver, Asoko, Mortimer, & Leach, 1995; Roth, Anderson & Smith, 1987).

More recently, inquiry has been viewed as having a discursive and relational dimension (Tobin, et al., 1997; Klaassen, et al., 1996) that complements the dimensions of critical thinking and individual skill with science processes. Studies of small group interactions have revealed the power of verbal expression and social interaction to promote student engagement. Teachers use small group interaction to stimulate discussion, increase engagement with materials, distribute responsibility for functions of activities, and distribute expertise around the class. These actions are particularly common in laboratory settings or during hands-on activities in science. Student understanding improves when small groups are structured through assigned roles and scripts for reviewing, rehearsing, and discussing results. (Cohen, 1994).

These effects most likely result from the increased engagement and higher level of discourse among all students resulting from the assigned roles of particular students. However, the teacher who provides too much structure for a task that is, by design, ill-structured may defeat the purpose of inquiry. Cohen (1994) stated a subtle but important dilemma for teachers that has implications for conducting small group instruction in science: If teachers do nothing but supply the task, the students may focus on the mundane or concrete features of the problem without exploring its more abstract and, presumably, more meaningful aspects. If teachers do too much by assigning roles and responsibilities, they may destroy opportunities for students to express novel approaches or ideas.

It is important to note in closing that inquiry-based instruction can have two meanings in practice. Inquiry-oriented instruction can mean teaching about the nature and processes of scientific inquiry, being in that sense a teaching outcome. Alternatively, it can mean that students learn science concepts by using the processes of scientific inquiry. In this sense it is a means to achieve an end. Teachers are more likely to use didactic teaching methods when teaching *about* inquiry by introducing key terms and providing guided practice. The application of inquiry as a teaching method is more likely to be indirect, with the teacher asking more open-ended questions and stimulating more student-to-student discussion (Brophy & Good, 1986).

3.3 Recommendations of the National Science Teachers Association

At the heart of inquiry is the ability to ask questions and identify solvable problems. Science education programs at the college and university level have traditionally focused more on the acquisition of content than on developing skills in questioning and problems-solving. Students at the graduate level often find their hardest task to be the identification of a researchable question for their theses and dissertations.

Students in science should engage in inquiry early in their science programs and should continue to inquire throughout their preparation. Having achieved a high level of comfort with inquiry in this way, students preparing tobe science teachers or specialists should face only the task of learning how to adapt inquiry for children.

The abilities to listen and to ask effective questions during teaching are skills that are not easy for most people to master. Effective listening and questioning skills are important to successful teaching in general and need not be confined to science methods instruction. In fact, as for inquiry per se, core preparation in listening and questioning skills before science-specific preparation might be the most effective and efficient approach to developing these skills. However, the ability to ask questions that are consistent with the conventions and processes of science must be developed specifically.

Because of the importance of questioning for inquiry, students throughout their early field experiences and student teaching should be highly sensitive to their questioning behavior. They should regularly analyze their own teaching to appropriately determine their strengths and weaknesses in questioning. Peer teaching may be useful but in a limited way, since adults may find it difficult to play the role of children effectively. Individuals preparing to be teachers should have as much experience as possible working with children. Beyond reactions from observers, self-analysis through audiotapes or videotapes including analysis of questioning behavior is highly recommended.

Inquiry demands skill in the analysis of data and assessment of results to reach reasonable and valid conclusions. As discussed in an earlier standard, students of science should be provided with regular opportunities for data analysis during their content preparation. They should acquire a reasonable level of proficiency in collecting and analyzing data in various formats (open and closed ended), and should be able to use scientific criteria to distinguish valid from invalid conclusions. Effective teachers can adapt teaching activities to create opportunities for inquiry from stock activities that are not focused on inquiry.

Since the social, collaborative nature of inquiry is important, students in science teacher preparation programs should be provided with opportunities to work together and apart. Strategies for group work, including rules to regulate work within project teams, should be part of instruction both in science course work and in education. Students entering teaching should provide evidence of effectiveness in organizing and working with inquiry groups.

Field experiences for prospective teachers should be broad. Programs should require evidence that their candidates can make good judgements regarding the capability of learners, and employ strategies for discovery learning, guided inquiry and open inquiry according to the experience of the learners and the context of the classroom.

The best teacher education programs exhibit strong integration of science with education. Content courses include opportunities for inquiry and regularly require critical thinking and the identification of researchable questions at an appropriate level. Data analysis is regularly required as part of the process of learning science rather than in support of the learning of content or in occasional laboratory activities. Science education courses and experiences with children document that candidates go beyond the mechanistic learning of the processes of science to a more holistic development of attitudes and disposition toward inquiry.

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